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http://scholarship.claremont.edu/scripps_theses/775

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**MARKET SENSITIVITY OF A HIGH FREQUENCY
TRADING FIRM STOCK**

by

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**SUBMITTED TO SCRIPPS COLLEGE IN PARTIAL FULFILLMENT OF
THE DEGREE OF BACHELOR IN ARTS**

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DECEMBER 11TH, 2015

Abstract

The major purpose of this study is to explore the stock movements of a publicly traded high-frequency trading firm, Virtu Financial. Virtu Financial, as of November 2015, is the only publicly traded high frequency trading firm, offering a opportunity to study the market behavior of a new kind of stock. Since Virtu serves as a unique financial intermediary, my hypothesis is that Virtu should be a market-neutral company since it is able to profit equally in economic upswings and downturns. This study uses a regression based on the Fama and French three factor model, focusing on the influence of the market risk premium, small sized company vs. medium sized company returns, and growth stock vs. value stock returns in changes in inter-daily Virtu Financial returns. These results are then compared to the returns of Virtu's brokerage competitors, as deemed so by analysts, and CBOE Holding, a company with . The results suggest that Virtu Financial has a market neutral stock, consistent with its means of generating revenue, while its traditional brokerage competitors do not. On the basis of this research, it is concluded that HFT brokerages may present an opportunity to invest in a non-cylcical segment of the finance industry.

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I.Introduction

A complex and often geographically disparate network of computers, algorithms, and high speed wires now dominate stock trading. The NYSE, for instance, has its data center, the NYSE Euronext, in Mahwah, New Jersey. Steady technological advances and actions by the Securities and Exchange Commission (SEC) helped create this modern trading environment. In the 1990s, heavy investment in technology made algorithmic trading profitable and relatively practical. Meanwhile, the SEC enforced several acts to encourage high tech trading, such as the Regulation Alternative Trading System Act (Aldridge 2013). With the increasing role of technology, speed and volume of trades became more important than ever. Instead of humans executing trades in minutes, computers could execute trades in mere milliseconds. This made it easier to arbitrage price differences in different markets, and companies with the infrastructure for this sort of speed experienced significant profits. The question was no longer who had the most information, but who could access information the fastest (James 2013). High speed, high volume algorithmic trading quickly grew to the level it is now, with 60% of all U.S. equity trades in 2011 being high frequency trades (Aldridge 2013). From small financial start-ups to the largest investment banks, financial firms are eager to pursue high frequency trading.

The current high frequency trading landscape is largely made up of business branches buried within a large institution, such as Citigroup, or small, privately funded proprietary trading groups. One company, however, has bucked the trend: Virtu Financial. In April of 2015, Virtu Financial became the first high frequency trading firm to have an IPO, and to this date remains the only publicly traded firm of its kind. The company already has a few regrets about its

publicity, with CEO Douglas Cifu lamenting the fact that an SEC filing revealed that since 2009, the company had only incurred trading losses on one day (Underhill 2015). Virtu can achieve these remarkable results by executing a high volume of trades with miniscule gains, e.g. \$0.0005 per share. The company makes money by connecting stock buyers to sellers and pocketing a portion of the spread between what the buyer is willing to buy for and what the seller is willing to sell for. Still, it is clear that the company's stock may behave in unusual ways given the limited information about and reputation of high frequency trading and the fundamental profit mechanisms of the practice. Usually companies have worse stock performances during volatile market periods and under regulatory action. Virtu Financial, however, is theoretically capable of performing well during volatile periods even if they occur during a downturn. The question is whether Virtu's stock reflects this idea.

This study examines Virtu Financial's (VIRT) day-to-day closing price returns from April 17th, 2015 to August 31st, 2015. Virtu's data will be run through a Fama and French three factor model along with returns on the VIX, a market volatility indicator. The VIX is based on S&P 500 option prices. If S&P 500 option prices rise this is because investors anticipate higher change in the S&P 500 in the future, and the VIX rises accordingly. Using the VIX will provide insight on which traditional market factors, including the market risk premium, have explanatory power over changes in Virtu Financial's returns, along with how much predictive power the VIX has on Virtu Financial. In theory, Virtu Financial's ability to generate revenue off of market volatility regardless of market health should be reflected in a market neutral stock, meaning a low and statistically insignificant market premium beta, or in other words, changes in the stock market cause little change in Virtu's stock. This is opposed to a market sensitive stock, which often have betas of one or higher. The VIX, may provide explanation if investors interpret

patterns in the VIX as indicative of higher volume trends since volatility is often correlated with trading volume. Higher volume and volatility lead to more and larger bid-ask spreads for Virtu to make revenue from. To provide further meaning to Virtu's return data, Virtu's regression results are compared to those of traditional brokerage competitors and the CBOE, another company with a market neutral revenue-generation model. The competitor comparison provides information on the risk exposure of Virtu vs. its competitors, while regressing CBOE returns provides an example of a company with similar risk exposure to Virtu.

II. Literature Review

Research on HFT firm stock behavior is limited. Existing research on HFT firms and strategies is largely related to how high frequency trading has impacted the market, such as increasing liquidity and creating new markets. Therefore, it is necessary to examine stock behavior research on other financial firms as a starting point for comparison. This literature review contains three parts: first, an examination of research on high frequency trading strategies and how they shape a hypothesis around Virtu Financial's stock behavior. This study hypothesizes that Virtu Financial's stock are market neutral because the company generates revenue based on volatility and volume. Secondly, this literature review analyzes market condition indicators, namely the VIX and the S&P 500. Finally, the relationship between companies in the financial industry and the S&P 500 is explored.

II.A. High Frequency Trading Definition and Strategies

The definition of high frequency trading and its key components vary in the literature. Speed is recognized as essential to HFT trading, but what constitutes speed differs. Aldridge (2013) defines HFT as having share holding times anywhere from a few milliseconds to a day, while Durbin (2010) limits this time frame to a few seconds at most. Brogaard (2010) simply defines this holding time as extremely short term. Other crucial characteristics proposed by research include real-time data processing, direct market access, and usage limited to institutional investors (Dacorogna et al, 2001). Multiple articles highlight the importance of HFT serving as a financial intermediary (Hendershott and Riordan, 2011). Other

researchers have noted that HFT strategies are usually implemented by broker-dealer proprietary trading desks, proprietary trading groups, and hedge funds (Goldstein et al, 2014). Virtu Financial may not satisfy every proposed detail by all existing literature on HFT, but it sufficiently hits the primary marks of trading large volumes at high speeds, as well as being a proprietary trading group.

HFT firms have historically outperformed the market overall on a risk-adjusted basis (Goldstein et. al, 2014). The companies that found the best strategies pursue active rather than passive tactics, meaning they exploited asset price disparities in fragmented markets, differences between different asset classes such as a derivative and its underlying assets, or discrepancies in pairs trading (Goldstein et al, 2014). The strong performance of HFT companies is likely related to the fact that they ultimately have limited exposure to the market. Like other financial intermediaries, high frequency traders have limited holding times and low inventory. A financial intermediary is any financial institution that serves as a middleman between two parties in a transaction. HFT firms go beyond traditional financial intermediaries by frequently “pinging” orders, meaning sending out small buy or sell orders to find price or liquidity discrepancies before immediately canceling these orders upon discovering an exploitable discrepancy (Goldstein et al, 2014). By limiting their holding time and only risking small share amounts at first, HFT traders limit their risk of capital losses due to decreases in the value of any stocks they hold over time . This bolsters the hypothesis that Virtu Financial will not be strongly affected by economic conditions or negatively affected by increases in volatility, and that its stock will show a similar pattern. If anything, Virtu may exhibit positive stock returns during higher volatility periods since it will have more opportunities to serve as an intermediary.

II.B. VIX and the S&P 500 as Market Indicators

While the S&P 500 predates the VIX by many years, both share many similarities. The Standard & Poor's 500 index consists of the five hundred largest American companies traded on the New York Stock Exchange and NASDAQ stock markets as measured by market capitalization. It is commonly used as a health indicator for the American stock market and economy. The Chicago Board Options Exchange Volatility Index (VIX) has a similar function but is more complex. The VIX as it is known today was created in 1993 and updated in 2003 by the CBOE and Goldman Sachs to have the S&P 500 as the underlying instead of the S&P 100. In brief, the VIX is based on the nominal value of 30-day variance swap rates on S&P 500 options. Because of this, the VIX is an indicator of implied, or future, market volatility rather than historic volatility. The VIX is commonly referred to as a fear gauge, because high implied volatility indicates expectations that the market will become unstable.

The relationship between the VIX and the S&P 100 or S&P 500 has been extensively studied. Overall, the two indexes are negatively correlated, meaning that a decrease in the VIX is tied to an increase in the S&P 500 and/or S&P 100 (Whaley, 2000). However, the relationship is not perfect. Whaley examined changes in the VIX and the S&P 100 from 1995 to 1999 using a simple OLS regression, and found statistically significant results. He found that if the VIX remained constant, the S&P 100 rose an average of 0.77% over the four years. If the VIX increased by 100 basis points, the S&P 100 fell 0.707% on average. These results indicate that

the VIX is a better gauge of fear of market downsides than a sign of excitement over market upsides.

Allen, Powel, McAleer, and Singh took a different approach in their 2012 article. While most studies used parametric methodologies to examine the VIX, Allen et al used non-parametric assumptions. Their entropy based non parametric tests found that the predictive power of the VIX for the S&P 500 was consistent overall, but during certain periods of time was less powerful, such as during a portion of the 90's tech bubble. Still, while certain studies have found complexities and variances in the relationship between the market and the VIX, the two are generally linked together in an inverse relationship. Thus, it is reasonable to examine the tie between the VIX and Virtu Financial since market volatility often comes with high trading volume, which HFT firms can make money from. An increase in the VIX, which would indicate anticipation of volatility and high trading volumes, may be linked to an increase in Virtu's stock price. Virtu's relation to the S&P 500 may be more complex. Certain macroeconomic factors that impact traditional financial firms like interest rates may decrease both the S&P 500 and standard financial stocks, but Virtu may be less sensitive to downturns at the end of a business cycle.

II.C. Financial Firms and the S&P 500

Financial companies are the largest sector in terms of market cap within the S&P 500, and continue to grow relative to other sectors. In 1990, the weight of the finance sector in the S&P 500 was 7.1%, while in 2011 it was 14.3% (Kriz, 2012). On average, finance companies have had higher returns and higher volatility than the market average, particularly during the

1990s bull market (Kriz, 2012). Research from the National Bureau of Economic Research (NBER) on a financial sector index and the S&P 500 also found that the finance sector is more sensitive to bear markets. For example, from 2007 to 2009, the financial sector composite fell 72% while the S&P 500 fell 47% (Kriz, 2012). This poses interesting implications for Virtu Financial. While Virtu is not the only financial intermediary in the public market, it does employ unique HFT strategies. It may differ from the typical financial firm which suffers during a bear market because of Virtu's dependence on trading volume, not returns. It is reasonable to predict that Virtu's stock is less cyclical compared to a finance sector index like the S&P 500 Financials.

III. Methodology

This methodology section covers the strategies undertaken to analyse Virtu Financial's stock. The section is thus divided into two parts. Part A explains the Fama and French regression model and why it is ideal for examining Virtu Financial's stock performance. Part B provides explanation on which companies are analyzed alongside Virtu Financial in this regression and why they were selected. Through regression and comparison to the results of other companies, Virtu Financial's changes in stock returns are given explanation and context.

III.A. Fama and French Model

The first stage of this study requires a traditional return model to indicate how sensitive Virtu Financial is to the market. Regression is needed to understand the relationship of Virtu Financial's stock returns and market conditions. The central formula used for this study is the Fama and French Three Factor Model:

$$r = R_f + \beta(Mkt - R_f) + \gamma SMB + \delta HML + \alpha$$

R_f , Mkt , SMB , and HML are inputs of the regression and r , β , γ , and δ are outputs of the regression. R_f is the risk free rate, Mkt is the daily return on the market. Subtracting the risk free rate from market return removes return bias from risk-free instruments like the one-month U.S. Treasury bill. This is an important step since this study only examines risk from the stock market, not bonds or other factors. SMB is the average return of small market capitalization companies minus large market capitalization companies, market capitalization being shares outstanding for a company times its stock price. HML is the daily return of value stocks minus the daily return of growth stocks, and α is the error term. As for the output terms, β is the volatility of the equity relative to the market, commonly known as beta. γ , or the size-loading

factor measures the relative importance of the SMB value. If the equity behaves like a small cap stock, which historically have higher returns according to the Fama and French model, γ will be higher and indicate a greater exposure to market cap size risk. δ , or the value loading factor, indicates the equity's exposure to value risk. If the stock behaves more like value stocks, which historically have a higher return, the value-loading factor will be higher. Finally, the error term accounts for error and unexplained factors that influence the daily returns of a particular stock holding. Compared to the traditional Capital Asset Pricing Model (CAPM), which equates returns on a stock to the risk free rate, beta times the difference of market returns and the risk free rate, and an error term, the Fama and French Model has superior explanatory power. While creating the model, French found that CAPM could explain 70% of a stock's behavior could be explained by CAPM while 95% could be explained by his three factor model (Fama and French, 1992). In other words, the Fama and French model is capable of generating a higher R squared value than CAPM. Because the subject of this paper is determining Virtu Financial's stock independence from market influence, it is vital to rule out prominent market biases like small cap stock performance compared to large cap and growth vs value equity.

The hypothesis of this study is that all three inputs- market returns, small cap returns minus large cap, and value returns minus growth-have little explanatory power for changes in the stock returns of Virtu Financial. That would imply that Virtu Financial is market neutral. Its competitors, which are not specialized high frequency trading firms, on the other hand, should exhibit less market neutrality. Within the model, market neutrality will present as a low R squared value and insignificant p-values for each input variable (a 5% significance level will be used for this study), as well as a low beta for the market risk premium ($Mkt - R_f$).

The second stage of this study adds in the input of VIX returns to the Fama and French model. Specifically, this addition to the model determines if the VIX has high explanatory power for Virtu Financial's daily stock returns, as shown by a higher R squared value and significant p-value for the VIX variable. , the slope coefficient tied to changes in the VIX, will indicate the stock's sensitivity and direction with the VIX. This paper's hypothesis is that is positive, meaning an increase in returns in the VIX is linked to an increase in Virtu Financial. Ameritrade, BGC Partners, and Raymond James Financial may have a significant and positive relationship as well since they also can profit off of trading volume, albeit not through the same mechanism as Virtu Financial.

III.B. Company Selection and Calculation of Returns

The companies for comparison, Raymond James Financial, AmeriTrade, and BGC Partners were chosen because they are commonly listed as comparable competitors for Virtu Financial on stock tracking websites like WallStreetJournal.com and Yahoo Finance. It should be noted that because Virtu Financial is the only publicly traded high frequency trading firm, none of these companies are direct competitors. In fact, AmeriTrade is known to pay HFT companies to execute AmeriTrade's client trade orders, making Virtu Financial more of a partner than a competitor. Still, these companies are the closest point of comparison on the public market. RJF is a financial holding company, with companies involved in equity and bond trading, underwriting, asset management, insurance sales, and other brokerage and financial services. It is therefore the most functionally diverse company studied. BGC Partners is a brokerage company divided into real estate and financial service segments. Its real estate

segment provides consulting, advisory, and management services related to real estate. Its financial services segment offers a range of brokerage and investment products such as interest rate swaps, trade execution, futures, and derivatives. AmeriTrade provides brokerage services with an emphasis on technology. Its best known product is tdameritrade.com, a trading platform for retail investors. The company also provides investment education and information through Trade Architect, as well as other services, like ETF portfolio creation.

The fourth company for comparison is CBOE Holdings, Inc. (CBOE). Since CBOE lists options and hosts an option exchange, the company is not a competitor for Virtu. Its most notable product is the VIX, a volatility index. Because the VIX tends to rise in times of market volatility and fall in times of stability, and options can similarly create strong investment opportunities in times of volatility, it is possible that CBOE's stock will exhibit similar patterns to Virtu Financial in that it will not be sensitive to changes in the S&P 500. It may even show a negative beta, meaning increases in the market (S&P 500) are tied to decreases in CBOE stock and vice versa. Thus its inclusion in this study is to show an example of a holding which may behave similarly to Virtu because its business model can also profit regardless of market conditions, rather than serving as a point of comparison for direct competition. Finally, General Motors (GM) serves as a control company in that if the Fama and French model is valid for this time period, it should return a statistically significant beta near one for GM. GM is well-known to have a moderate amount of market risk. If the regression can pick up on market risk, it should pick up on the well-established market risk of GM.

Each holding's daily opening price, daily closing price, daily trading volume, daily high price, and daily low price was downloaded from historical price tables provided by The Wall

Street Journal website. Book-to-market ratios were calculated using financial data from company SEC filings for the third quarter and market cap values on November 13th, 2015. The calculation includes total assets minus total liabilities for the book value and total shares outstanding times stock price for the market value. Daily returns on the holdings were calculated by taking the difference between the closing price of one day and the day before and dividing it by the previous day's price and multiplied by one hundred to obtain a percentage figure. For example, Virtu Financial's closing price on September 30th 2015 was \$22.92 and \$23.01 on October 1st 2015, so its daily return was around 0.004 or 0.4 percent.

IV. Data

This study required stock performance data of the companies Virtu Financial (VIRT), AmeriTrade (AMTD), Raymond James Financial (RJF), BGC Partners (BGCP), General Motors (GM), and CBOE Holdings (CBOE) as well as the performance of the CBOE Volatility Index (VIX). The regression required inputs of the risk free rate, market return, SMB factor, and HML factor. This data section covers descriptive and summary statistics of the companies selected, factor data for the Fama and French model, and the time frame used for the study.

IV.A. Time Frame and Fama and French Data

The time period used for all holdings is April 16th, 2015 through August 31st, 2015. The beginning date was chosen because it is the day of Virtu Financial's IPO. While stocks can behave somewhat erratically shortly following IPO, due to the limited time frame, near-IPO returns of Virtu were used in order to provide the longest possible period of time to study the relationship of Virtu's stock and the market. The end of the time frame, August 31st, was the last date on which daily Fama and French three factor model data is provided on the Fama Data Library website as of October 15th, 2015.

The Fama and French data consists of five items: the date, the market return minus the risk free rate, the SMB value, the HML value, the risk free rate. From April 16th to August 31st the risk free rate was zero, with the rate of return on a one-month Treasury bill serving as the risk free rate. Thus, the market return minus the risk free rate is equal to the U.S. market returns as measured by the daily return for the S&P 500 index controlled for dividend effects minus the one

month Treasury bill rate of return. The Small market cap Minus Big (SMB) is the daily return of a U.S. small cap index minus the daily return of a US large cap index. The High book-to-market ratio Minus Low (HML) is the difference between returns of value and growth stocks.

IV.C. Descriptive and Summary Statistics for the Companies

Table 1 compares the market capitalization, beta, and book to market ratio of Virtu, the three competing companies, and CBOE. The weighted average and average values are calculated only using Virtu, RJF, BGCP, and AMTD. The weighted average is weighted based on market cap calculated on October 12th, 2015 data on shares outstanding and stock price. Beta is derived from the Fama and French test run in this study and indicates each stock's return variance as explained by the difference between the S&P 500 and the risk free rate with dividends controlled for. The book to market ratio was calculated by taking total assets of each company for the third quarter and subtracting total liabilities, and then dividing this value by the market cap of the company. This ratio provides information on whether a stock is a growth or a value stock relative to the rest of the field, which is relevant for two factors in the Fama and French model. Since value stocks are called such because they are considered undervalued, they should have higher book to market ratios, indicating a higher book value relative to the market-determined value of the company.

As Table 1 shows, Virtu Financial has a significantly smaller market capitalization than its competitors, with its market cap more than twelve billion dollars less than the weighted average. In this case the unweighted average may be more pertinent since the size of AmeriTrade at \$17.3 billion is much higher than the other companies. Virtu's beta is much smaller than any of the other companies. Virtu has the highest book to market ratio, indicating

that it is the most like a value stock compared to the rest of the field. However, given that book to market values can vary depending on the industry and Virtu Financial does not have the same business model of the other companies, regression is necessary to better understand whether Virtu Financial moves as a growth or value stock.

Descriptive analysis of VIRTU, BGCP, RJF, AMTD, and CBOE reveals interesting patterns and differences between the companies. Table 2 presents these results. CBOE and Virtu Financial both have the highest mean and median inter-daily returns of all the companies. This may be because both of these firms have relatively market-neutral business models while Ameritrade, Raymond James Financial, and BGC Partners are more cyclical. Since the market overall did not fare well during this time period, it makes sense that the companies with less vulnerable revenue means to the market would take less of a hit than those that are more vulnerable. Virtu Financial also had the highest or second highest kurtosis, sample variation, and standard deviation, along with BGC Partners. Without running the regression, these descriptive results may lead to the conclusion that Virtu Financial is more market sensitive since higher beta stocks tend to have higher variance on average. Thus, the Fama and French model is needed to analyze the explanatory variables for Virtu Financial's volatile movements relative to its competitive peers and CBOE.

Table 1. Company Market Cap, Beta, and Book to Market Values

Company	Market Capitalization	Beta	Book to Market (Q3)
Virtu Financial	\$804,080,000	-0.01	0.70
BGC Partners	\$2,060,000,000	1.29	0.48
AmeriTrade	\$17,300,000,000	1.26	0.25
Raymond James Financial	\$7,370,000,000	1.30	0.59
Average	\$6,883,520,000	0.96	0.50
Weighted Average	\$13,020,120,688	1.24	\$0.37
CBOE Holdings Inc	\$5,400,000,000	0.11	0.05

Table 2. Descriptive Statistics

<i>Measure</i>	<i>VIRTU</i>	<i>BGCP</i>	<i>RJF</i>	<i>AMTD</i>	<i>CBOE</i>
Mean	0.084	-0.084	-0.073	-0.089	0.088
Standard Error	0.210	0.230	0.143	0.154	0.106
Median	0.047	-0.312	0.133	-0.215	0.087
Standard Deviation	2.046	2.239	1.392	1.499	1.034
Sample Variance	4.186	5.012	1.938	2.246	1.069
Kurtosis	7.361	6.911	3.811	1.759	0.739
Skewness	-1.272	1.682	-0.944	-0.017	0.264
Range	15.417	16.529	10.015	10.000	6.173
Minimum	-10.748	-5.227	-5.963	-4.971	-2.554
Maximum	4.669	11.301	4.052	5.029	3.619

V. Results

This section covers the results and interpretation of the regression analysis on Virtu Financial. The first sub-section discusses the figures derived from running the Fama and French regression on the inter-daily returns of General Motors. Since General Motors is established as a traditionally cyclical stock by prior economic research, regression results concordant with this discussion indicate that the model picks up market sensitivity. Additionally, this test also helps identify whether the time frame studied is representative of typical market conditions. The second sub-section discusses the regression results and statistical significance for Virtu Financial, Ameritrade, BGC Partners, Raymond James Financial, and CBOE. Next, there is a discussion of Virtu Financial's results when a VIX factor is added to the model. The final sub-section examines Virtu's data to detect excess return outliers to determine if outlying data may have created less accurate regression results.

V.A. Initial Test on a Traditional Stock

To first test the validity of the Fama French model for this study, inter-daily returns for General Motors (GM) stock were examined to serve as an example of a traditional cyclical stock. The results can be seen in Table 3 and are consistent with expectations for GM. GM has a beta of 1.109 with a p-value well below a maximum of 0.05. GM also had a statistically significant HML value of 0.518 (Table 3). This HML value indicates that GM was sensitive and benefitted from the return bias of value stocks over growth stocks. Along with a moderate R

squared value of 0.489, the regression output indicates that movements of GM stock are fairly tied to movements in the overall market. Extensive examination of GM stock movements is not needed for the purpose of study; these results merely indicate that the model chosen is able to detect a stock which is well-known to not be market neutral.

Table 3. Regression results for GM

	Coefficient	Standard Error	P-Value
Intercept	-0.154	(0.115)	0.182
Mkt-Rf	1.109	(0.115)	0.000
SMB	-0.098	(0.278)	0.726
HML	0.518	(0.208)	0.015
R Squared	0.489		

V.B. Results for Virtu Financial, Competitors, and CBOE

The regression results of VIRT are consistent with the hypothesis that Virtu Financial's stock is not sensitive to the market. As Table 4 shows, Virtu Financial had a slightly negative beta at -0.011. This indicates that a one unit rise in the market premium, $Mkt - R_f$, is associated with a 0.011 decrease in VIRT inter-daily returns. As seen in Table 5, the p-value for this coefficient is high, indicating that this relationship is not statistically significant as the t value is well out of the critical region. Both the low beta and high p-value point to market neutrality. The intercept, SMB, and HML are also all statistically insignificant, indicating that none of these factors are adequate predictors for VIRT holding movements. This is again concurrent with a market neutral hypothesis, as neither the standard SMB or HML market biases sufficiently predicted changes in VIRT. Collectively, these variables resulted in a low R squared

value of 0.009, showing that this model does little to explain changes in VIRT over the time period.

AMTD, BGCP, and RJF all have statistically significant betas with values over one (Table 4, Table 5). A significant beta over one indicates that a stock is sensitive to the market and is volatile relative to the market, meaning a one unit increase in the market premium is tied to a greater than one unit increase in the stock. These results are expected given industry trends; brokerages tend to be cyclical, market-sensitive stocks. There is more variation between the companies when it comes to the SMB and HML values. All three SMB values were fairly close, with BGCP having the lowest at 0.234 and RJF the highest at 0.372, but only RJF's SMB value was significant with a p-value of 0.047, putting it within a 5% confidence level (Table 5). This result is interesting given that RJF has a higher market cap than BGCP (Table 1). The regression indicates that despite RJF having a moderate market cap, RJF stock movements are tied to overall market movements in small cap companies, which tend to earn a higher return on average. HML coefficients exhibited more variation than SMB coefficients. RJF had the lowest HML coefficient at 0.178, while AMTD had the highest at 0.535 (Table 4). Table 5 shows that none of these HML values are statistically significant. AMTD, RJF, and BGCP had moderate to strong R values at 0.614, 0.294, and 0.787, respectively (Table 4). These R squared values indicate that the Fama and French model have decent predictive power for the inter-daily returns of the companies over the examined time period, results that are concurrent with their industry class. Comparing the regression results of Virtu Financial and Raymond James Financials, BGC Partners, and AmeriTrade reveals clear differences between the two groups. All three factors, $Mkt - R_f$, SMB, and HML had statistically insignificant coefficients for VIRT combined with a low R squared value. In contrast, all three competitors have highly significant market premium

betas and moderate to strong R squared values. These differences indicate that Virtu Financial's stock does not move in a similar pattern to its supposed public market competitors.

One company that yields results similar to Virtu Financial in this study is CBOE. CBOE's beta for the time frame of April 17th through August 31st is 0.113, which is low and indicates that CBOE moves more like a risk free asset, which would have a beta of zero, than the equity market (Table 4). Additionally, this beta has a p-value well above the statistically significant level of 0.05, with a value of 0.598 (Table 5). Unlike any of the other companies studied, the CBOE has negative SMB and HML values of -0.041 and -0.255 (Table 4). Negative coefficients for these factors imply that movements in CBOE behave more similarly to large cap stocks and growth stocks than small cap stocks and value stocks. That said, both of these factors have p-values beyond statistical significance, at 0.905 and 0.556 respectively (Table 5). High p-values mean that the negative coefficients may not be indicative of CBOE's inter-daily return movements. Like Virtu Financial, CBOE had a low R squared value, at 0.022 (Table 4). Overall, these results indicate that CBOE behaves like a market neutral stock, which is consistent with its market neutral business model since the CBOE sells the VIX, a product based on volatility rather than strong or weak economic conditions.

Table 4. Regression Results for VIRT, Competitors, and CBOE

	VIRT	BGCP	RJF	AMTD	CBOE
Intercept	0.098	0.013	0.021	0.010	0.030
	(0.214)	(0.198)	(0.068)	(0.098)	(0.127)
Mkt-Rf	-0.011	1.293	1.304	1.260	0.113
	(0.231)	(0.213)	(0.073)	(0.106)	(0.212)
SMB	0.418	0.234	0.372	0.326	-0.041
	(.470)	(0.434)	(0.148)	(0.215)	(0.338)
HML	0.055	0.468	0.178	0.535	-0.255
	(.479)	(0.443)	(0.151)	(0.219)	(0.430)
R squared	0.009	0.294	0.787	0.614	0.022

Figure 5. P-values for VIRT, Competitors, and CBOE

	VIRT	BGCP	RJF	AMTD	CBOE
Intercept	0.564	0.926	0.720	0.887	0.811
Mkt-Rf	0.950	0.000	0.000	0.000	0.598
SMB	0.420	0.393	0.047	0.296	0.905
HML	0.870	0.221	0.185	0.150	0.556

V.C. Results Using Additional VIX Factor

The next regression examines the impact of adding in the inter-daily returns of the VIX to the regression on VIRT returns. Table 6 presents these results. Overall, the VIX factor does not create large changes in the coefficients, significance levels, and the R squared value. The market risk premium beta went from a slightly negative to a slightly positive number, but its p-value is still well beyond standard significance levels. The VIX factor had a small coefficient at 0.008

and a high p-value of 0.774, indicating that it does not have substantial explanatory power for movements in VIRT. The R squared value reflects the insignificance of these variables collectively; sitting at a low 0.010, it is only slightly higher than the regression without the VIX. Ultimately these results indicate that if there was an opportunity to achieve unrealized capital gains in VIRT by investing in it before or when the VIX rises during the examined time frame, it was unrealized on an inter-daily basis. Investors may be unaware of this opportunity or think, rightly or wrongly, that the VIX is not a good metric of increasing trading volume that will positively impact Virtu's revenue and long term revenue potential

Table 6. Regression Results for Virtu Financial with VIX Factor

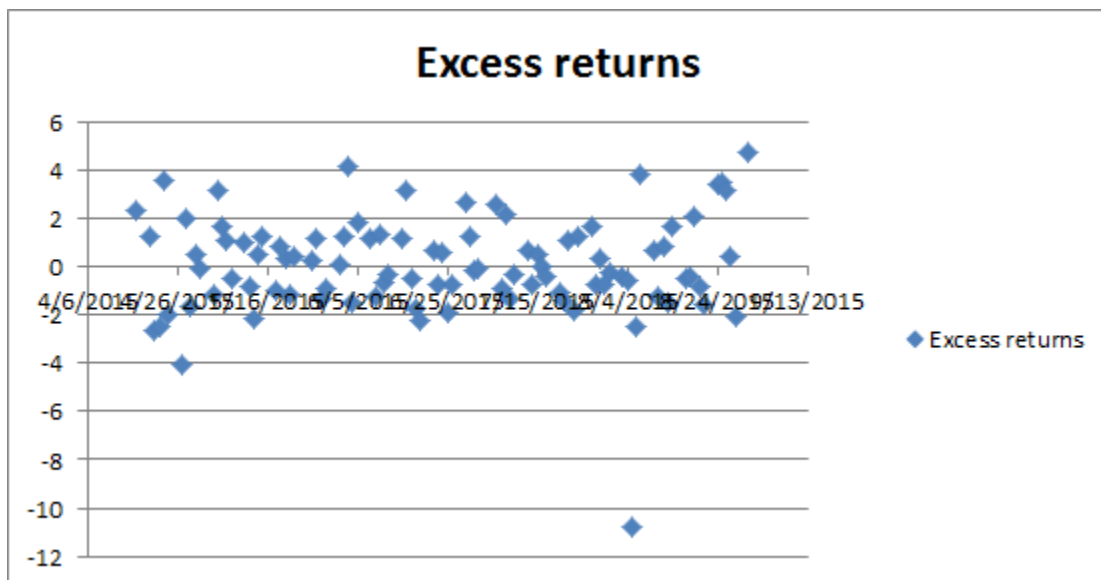
	VIRT	p-value
Intercept	0.091	0.588
	(0.167)	
Mkt-Rf	0.064	0.826
	(0.288)	
SMB	0.413	0.423
	(0.513)	
HML	0.041	0.901
	(0.324)	
VIX	0.008	0.774
	(0.027)	
R Squared	0.010	

V.D. Detection of outliers and excess returns for Virtu Financial

One potential limitation of the regression is that the Virtu Financial return data contained a few outliers which would conceal a market-following pattern. In order to rule this out, an

excess returns model is used. Excess returns are returns beyond expected returns given that period's market premium and the stock's beta. Excess return calculations use a CAPM-based formula: $Er = Kr - (b * [Mkt-Rf])$, where Er is the excess return for that day, Kr is the total return for that day, b is beta derived from the regression results, and $[Mkt-Rf]$ is the same market premium used in the Fama and French model. Virtu Financial's excess returns are presented in Figure 1 below. As shown, there are few blatant outliers, most excess return values are in the negative two percent to four percent range. Thus, it is reasonable to conclude that outliers have not significantly distorted the validity of the regression results.

Figure 1. Virtu Financial Excess Returns



VI. Conclusion

Virtu Financial presents a unique opportunity to study the stock movements of a high frequency trading company, a method which involves using algorithms to trade large volumes at high speeds to take advantage of small pricing spreads. Brokerages, which are listed as competitors to Virtu on financial websites, are relatively vulnerable to economic cycles, while high frequency trading firms make money almost exclusively based on trading volume regardless of whether the market is going up or down. If a stock is a representation of individual's expectations of a company's future cash flows, as rational market theory dictates, Virtu Financial's stock should reflect this difference. Using a Fama and French model allows insight on VIRTU inter-daily stock movement relative to traditional market factors: the risk free rate, the market risk premium, the market bias for small cap businesses, and the market bias for value over growth equities. If VIRTU moved in a way that is logical given Virtu Financial's business model, running that regression should yield insignificant coefficients on each factor and a low R squared value overall under rational market theory assumptions. Furthermore, if the VIX, a gauge of future volatility, may be a significant predictor for inter-daily movements of VIRTU stock.

The results of this study are consistent with the hypothesis that traditional market factors have low predictive power for movements in Virtu Financial's stock. All of the coefficients in the Fama and French model had highly insignificant p-values. The market risk premium coefficient also known as beta had a near zero, slightly negative value. A beta close to zero indicates a market neutral stock, meaning VIRTU would not move based on movements of the S&P 500 index. Adding the VIX into the model did not explain movements in VIRTU either,

yielding a VIX coefficient with a high p-value. All three competitors, BGCP, AMTD, and RJF, had significant market risk premium factors with betas around one. Interestingly, the only company with a significant SMB value was RJF, which is not the smallest company of the three based on market cap. Ameritrade was the only company with a significant and positive HML, indicating stock returns similar to companies with high book-to-market ratios, also known as value stocks. This is somewhat surprising given the sheer size of AMTD and its market valuation. Overall, these results indicate that Virtu Financial stock is not vulnerable to the same market risks of its competitors; its competitors behave cyclically while Virtu does not. GM, used as an example of a company in a traditional market-sensitive industry, had the expected regression results of a significant beta close to one, which helps solidify the validity of using the Fama and French model to study various stock patterns. Finally, CBOE, a company which is capable of profiting off of market volatility, although through different means than Virtu, had expected regression results. The three factors had insignificant explanatory power for inter-daily CBOE returns. Overall, the results of this study indicate that Virtu Financial stock is not vulnerable to the same market risks of its competitors; its competitors behave cyclically while Virtu does not. Virtu stock moves most similarly to CBOE.

While the results of this study are intriguing, there are several limitations. The primary weakness of this research is the small sample size. Virtu Financial is the only publicly traded firm specialized in high-frequency trading. Its stock behavior results, namely market neutrality, may not be applicable to future publicly traded HFT companies. There may be characteristics of Virtu Financial that other public HFT firms would not share. Another sample size limitation relates to time. Virtu Financial has not been public for long, having its initial public offering in April of 2015. The nature of its inter-daily stock returns may change as the company matures, so

the time period of mid-April 2015 to the end of August 2015 may not have been enough time. This study also did not control for events which could have resulted in erratic stock movement unrelated to the market, such as the few days following IPO, quarterly earnings announcements, and news events specific to Virtu Financial and HFT such as announcements of regulatory action around algorithmic trading. These limitations could potentially be controlled by using a dummy variable for certain events or simply not using the stock return data related to the abnormal period. The issues of only having one company to study, as well as a minimal time frame, cannot be fixed with the model and simply require waiting for time to pass and more HFT companies to go public.

Virtu Financial's stock presents an opportunity to study a new type of firm in the publicly traded realm. Quantitative analysis of the stock, especially by studying its movement relative to changes in the market and market volatility, provides insight on how this particular high frequency trading firm interacts with the macro environment. Stock prices and movements in stock values ultimately reflect people's expectations of a company's future cash flows rather than purely demonstrating the company's fundamental value. A market neutral stock, as this study has indicated, shows investor sentiment that Virtu Financial's business is not sensitive to traditional economic cycles, even compared to brokerage competitors. A stock with a beta near zero can be an extremely valuable portfolio holding, as its value is more likely to remain steady while stocks with betas of one or higher may drop when the market weakens. It is difficult to extrapolate the study results on Virtu Financial to all future HFT firms, but understanding how Virtu stock moves now is valuable information for investors and academics alike.

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